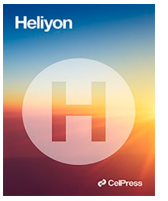
Heliyon 9 (2023) e20760

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Feasibility of new patient dose management tool in digital radiography: Using clinical exposure index data of mobile chest radiography in a large university hospital

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ARTICLE INFO

Keywords:
Dose management
Exposure index
General radiography
Optimization
Patient dose

ABSTRACT

The clinical anteroposterior (AP) chest images taken with a mobile radiography system were analyzed in this study to utilize the clinical exposure index (EI) as a patient dose-monitoring tool. The digital imaging and communications in medicine header of 6048 data points exposed under the 90 kVp and 2.5 mAs were extracted using Python for identifying the distribution of clinical EI. Even under the same exposure conditions, the clinical EI distribution was 137.82–4924.38. To determine the cause, the effect of a patient's body shape on EI was confirmed using actual clinical chest AP image data binarized into 0 and 255-pixel values using Python. As a result, the relationship between the direct X-ray area of the chest AP image, the higher the clinical EI, the larger the rate of the direct X-ray area. A conversion equation was also derived to infer entrance surface dose through clinical EI based on the patient thickness. This confirmed the possibility of directly monitoring patient dose through EI without a dosimeter in real-time. Therefore, to use the clinical EI of the mobile radiography system as a patient dose-monitoring tool, the derivation method of clinical EI considers several factors, such as the relationship between patient factors.

1. Introduction

Since the digital radiography (DR) system was introduced in medical radiology, progress has been made in diagnostic imaging, such as obtaining a constant gray-level image regardless of the degree of X-ray exposure through digital image processing [1–3]. This is

Abbreviations: DR, Digital radiography; IEC, International Electrotechnical Commission; EI, Exposure index; DICOM, Digital imaging and communications in medicine; RQA, Radiation beam quality; EI_T, Target exposure index; DRLs, Diagnostic reference levels; AEC, Automatic exposure control; AP, Anterioposterior; kVp, kilovoltage peak; ROI, Region of interest; SD, Standard deviation; ESD, Entrance surface dose; DAP, Dose area product; SID, Source-to-image receptor distance; DI, Deviation index.

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https://doi.org/10.1016/j.heliyon.2023.e20760
Received 29 March 2023; Received in revised form 26 September 2023; Accepted 5 October 2023
Available online 7 October 2023

expected to reduce the medical radiation exposure of the public. However, in reality, they tend to be exposed to a higher dose to improve the signal-to-noise ratio according to the characteristics of the digital image [4,5].

The International Electrotechnical Commission (IEC) recommends monitoring the patient's dose during X-ray examinations [6,7]. Accordingly, DR system manufacturers provide exposure indicators developed using their methods [8,9]. Notably, several attempts have been made to monitor the radiation dose using these indicators [10,11]. However, the exposure indicators have various relationships with the dose incident on the detector, such as proportional, inverse-proportional, and logarithmic, depending on the manufacturer [8]. Therefore, it is difficult to use exposure indicators as a radiation dose-monitoring tool in the clinical environment.

The IEC defined the exposure index (EI), a unified indicator according to international standards, in addition to the indicators provided by the manufacturer, and established a framework for using EI through IEC 62494-1 [12]. The EI is proportional to the dose incident on the detector of the DR system [12]. Per the IEC, the EI was introduced in digital imaging and communications in medicine (DICOM) and is stored in the DICOM tag (0018,1411) when manufacturers of DR systems provide the EI [13]. Currently, several DR system manufacturers provide the EI per the IEC on the console, and their exposure indicators [14,15].

The calibration method for EI is stipulated in IEC 62494-1; however, it does not describe a method for deriving EI for patient examination (hereafter, 'clinical EI') in a clinical environment [12]. Therefore, the clinical EI values for each examination protocol may differ for each manufacturer [15,16]. However, the clinical EI also shows a proportional relationship with the incident dose on the detector [15,17]. Therefore, several studies have demonstrated the utility of the EI as a real-time dose-monitoring tool [14–18].

A previous study reported that the EI could be used as a quality control tool for the detector through the relationship between EI and air kerma incident on the detector under radiation beam quality (RQA) 5, a calibration condition according to the IEC standard [14]. In addition, the possibility of using clinical EI as a dose-monitoring tool was suggested by setting an appropriate target exposure index (EI_T) based on national diagnostic reference levels (DRLs) [15,17]. A study was conducted on the considerations when using EI as a dose monitoring tool in clinical practice through the change in EI according to the patient's thickness in an environment where an automatic exposure control (AEC) system is applied [18].

This study analyzed the actual application environment of the EI for clinical anteroposterior (AP) chest radiography images taken with a mobile radiography system, which includes EI in DICOM. Then, the effective use of clinical EI as a patient dose-monitoring tool was presented based on the analyzed data.

2. Materials and methods

2.1. Extracting DICOM header data

In this study, X-ray images taken with a mobile radiography system (OPTIMA XR220B; GE Healthcare, Wisconsin, Waukesha, USA) and a wireless digital detector (Flash pad HD3543; GE Healthcare) including the EI as per IEC standard in DICOM, were analyzed. This study was approved by the Institutional Review Board (IRB) of Dong-A University Hospital (DAUHIRB-22-035). This study design is retrospective, and the data was analyzed after anonymizing the patient's personal information, therefore the IRB review waived the patient's consent.

Table 1
DICOM tags extracted from chest anteroposterior images for clinical exposure index analysis.

Tag	Name	Value Example
(0008, 0020)	Study Date	20211122[a]
(0008, 0030)	Modality	CR[b]
(0010, 0040)	Patient's Sex	F[c]
(0010, 1010)	Patient's Age	20Y
(0018, 0060)	kVp	90
(0018, 1030)	Protocol Name	CHEST_AP
(0018, 1149)	Field of View Dimensions	[341, 417][d]
(0018, 1150)	Exposure Time[e]	15
(0018, 1151)	X-Ray Tube Current[f]	200
(0018, 1152)	Exposure[g]	3
(0018, 1166)	Grid	NONE
(0018, 1411)	Exposure Index	352.21
(0018, 1412)	Target Exposure Index	624
(0018, 1413)	Deviation Index	−2.48
(0018, 6000)	Sensitivity	475.27
(0018, 7060)	Exposure Control Mode[h]	MANUAL

[a] YYYYMMDD.
[b] CR: Computed Radiography.
[c] F: Female, M: Male, O: Other.
[d] [width, length]/unit: mm.
[e] unit: msec.
[f] unit: mA.
[g] unit: mAs.
[h] Automatic Exposure Control (AEC)/Manual means AEC mode not applied.

For 8045 chest AP images taken with the mobile radiography system for 6 months from June 1 to December 31, 2021, only the information necessary for analysis from the DICOM header was extracted using Python (v3.9.12). The extracted information was as follows: study date, modality, patient's sex, patient's age, kilovoltage peak (kVp), protocol name, a field of view dimensions, exposure time, X-ray tube current, exposure (mAs), grid, exposure index, target exposure index, deviation index, sensitivity, and exposure control mode. The DICOM tag numbers are listed in Table 1.

The tube voltage range of 8045 chest AP images varied from 50 to 120 kVp, and the tube current exposure time product range varied from 1 to 16 mAs. Among these, data on the most frequent exposure conditions were used for this study.

2.2. Relationship between clinical EI and patient area

The EI is defined as the measurement of the detector's response to radiation within an appropriate image area, as per the IEC, and is calculated using equation (1) [12].

$$EI = C_0 \times g(V) \tag{1}$$

where, C_0 is a constant of 100 μGy^{-1} and g(V) is an inverse calibration function, which is the inverse function of the value of interest V [12]. In other words, the EI is a function of the effective value of interest in the image exposed to calibration conditions. It expresses the dose incident on the detector [12,14]. According to equation (1), the EI is proportional to the dose incident on the detector. Therefore, under the same exposure conditions, the incident dose on the detector is the same; thus, it is ideal for the EI to have the same value [14].

However, the EI of the radiographic images used in this study showed various distributions. Even if the same dose was exposed, the EI could vary due to the difference in the detector's incident dose depending on the patient's body thickness through the phantom experiment in a previous study [18,19]. Accordingly, in this study, the effect of a patient's body shape on EI was confirmed using actual clinical image data.

Using the cv2.threshold function of the Python image processing library Open CV for 100 images for each section, 8-bit binary images were created. The threshold of the pixel value applied for binarization was 40, the pixel value of the direct X-ray area was 0, and that of the patient area was 255. The threshold value was empirically adopted as the value from which the patient's body shape was clearly extracted. Fig. 1 shows a example of a before binarization (Fig. 1 (a)) and a after binarization with threshold 40 (Fig. 1 (b)). Then, the number of pixels in the area corresponding to pixel values 0 and 255 were counted through the numpy.count non-zero function of the Python numpy library. The proportion of the area occupied by the patient's body in the image was identified, and the relationship with clinical EI was analyzed.

2.3. Derivation of entrance surface dose from clinical EI

Previous studies are being conducted to monitor the patient dose using EI as per the IEC standard [14–18]. This study conducted, additional experiments to utilize clinical EI to monitor the patient dose. Based on the result that clinical EI varies according to patient body shape under the same exposure conditions confirmed through previous studies [18] and data analysis in section 2.2 of this paper, the conversion formula was developed to derive the entrance surface dose (ESD) from clinical EI.

The X-ray was exposed using the same mobile radiography system and under the same exposure conditions (90 kVp, 2.5 mAs) with clinical data. The bolus (BOLX-II, Radiation Products Design, Inc., Minnesota, USA) was added to the whole-body phantom (PBU-60, Kyoto Kagaku Co., Ltd, Kyoto, Japan) at 0, 2, 4, and 6 cm thicknesses, and the ESD was measured, along with the identification of clinical EI value which is displayed on the console of mobile radiography system (Fig. 2). A semiconductor dosimeter (RaySafe Xi, Unfors RaySafe AB, Billdal, Sweden) was utilized for ESD measurement. Unfors RasySafe AB calibrated this dosimeter on June 8th,

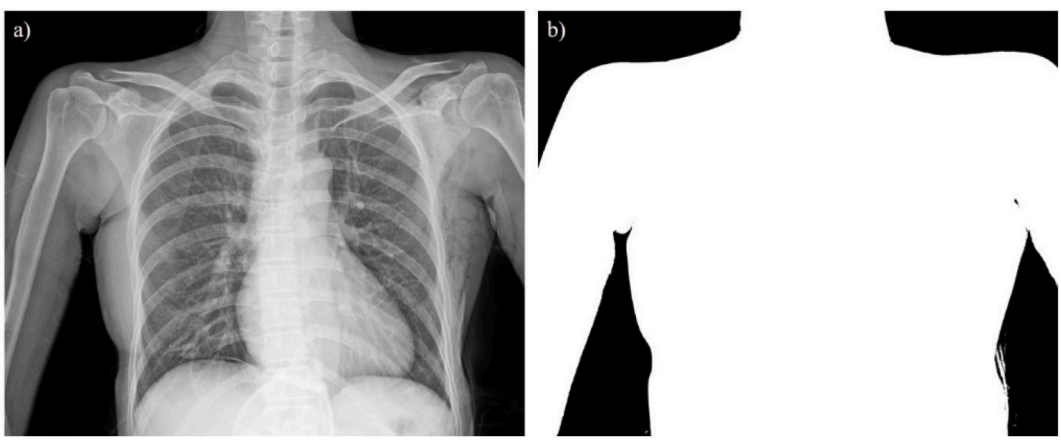

Fig. 1. Example of binary image (a) before and (b) after binarization with threshold 40.

2021. Then, each relational expression for the relationship between the phantom thickness and ESD and between the phantom thickness and clinical EI was identified. These two relational expressions were solved simultaneously to establish a conversion equation that enables the calculation of ESD using clinical EI as a parameter. The established conversion equation was applied to 6048 clinical data to calculate each patient's ESD.

3. Results

3.1. Distribution of clinical EI identified through DICOM header data

Among the 8045 chest AP images taken with the mobile radiography system during the analysis period, 6480 (80.5 %) were taken with a tube voltage of 90 kVp. Among the 90 kVp chest AP images, there was one case with a 2 mAs exposure, 6048 with 2.5 mAs, 415 with 4 mAs, 15 with 5 mAs image, and one with 6 mAs. The most frequently examined exposure conditions were identified as 90 kVp and 2.5 mAs; therefore, 6048 data points exposed under the corresponding conditions were used for analysis (Table 2).

A histogram of the number of 6048 data points for each clinical EI in Fig. 3. And Table 3 shows the results of the analysis of clinical EI values included in the DICOM headers of the images. The minimum and maximum clinical EI values were 137.82 and 4924.38, respectively. The mean clinical EI was 674.46 ± 239.47. There were 3311 male cases, 2721 female cases, and 16 'other' cases. 'Other' is an attribute of the DICOM tag (0010,0040) and includes sex that cannot be identified or a transgender person [20].

In the case of male EI distribution, the minimum and maximum values were 137.82 and 3069.18, respectively, and the mean male EI was 619.11 ± 239.47. The minimum and maximum values for female EI distribution were 174.56 and 4924.38, respectively, and the mean female EI was 742.30 ± 260.56. The minimum and maximum EI values for 'other' cases were 233.15 and 860.26, respectively, and the mean 'other' EI was 590.84 ± 202.74.

The regression analysis investigating the relationship between sex and clinical EI revealed a coefficient of determination of 0.062. This indicates that the variation in clinical EI attributed to sex is relatively low, suggesting a weak causal relationship between sex and the value of clinical EI.

3.2. Relationship between clinical EI and patient area

The pixel values of the images were binarized into 0 and 255, and the relationship between patient area and clinical EI was identified. The relationship between the clinical EI and the rate of the patient area is shown in Fig. 4. The correlation coefficient between clinical EI and the rate of the patient area in the chest AP image was found to be 0.455 ($p < 0.001$). This indicates a moderate positive correlation between clinical EI and the patient area in the image. Fig. 5 shows a representative binary image of a low clinical EI (Fig. 5 (a)) and a high clinical EI (Fig. 5 (b)). As shown in Figs. 4 and 5, the direct X-ray area increased, and the patient area decreased when the clinical EI increased.

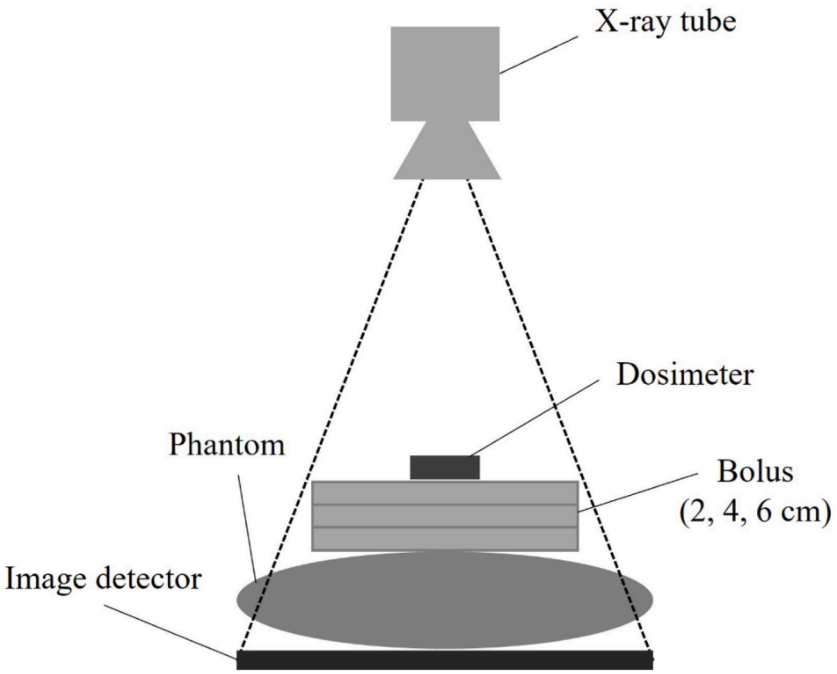

Fig. 2. Experimental setup for obtaining entrance surface dose and clinical exposure index.

Table 2
Image data information used for analysis.

Study date		2021.06.01. ~2021.12.31.
Tube voltage (kVp)		90
Tube current time product (mAs)		2.5
Protocol name		Chest AP
Patients mean age (y)		70 ± 14.01
Sex (N)	Male	3311
	Female	2721
	Other[a]	16
Total data (N)		6048

[a] Other: including transgender, hermaphrodites, and a person who could not be identified by sex.

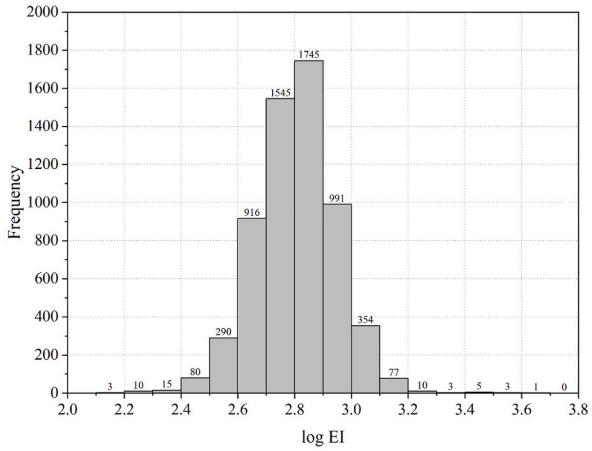

Fig. 3. Histogram of the number of data for each clinical exposure index of chest anteroposterior images taken under the same exposure conditions of 90 kVp and 2.5 mAs with a mobile radiography system during the period of from June 1 to December 31 in 2021.

Table 3
Clinical exposure index distribution for chest anteroposterior images taken with a tube voltage of 90 kVp and tube current exposure time product of 2.5 mAs.

	N	EI-min	EI-max	EI-mean (95 % CI)[a]	EI-SD[b] (95 % CI)
Total	6048	137.82	4924.38	674.46 (668.20–680.51)	239.47 (223.27–258.21)
Male	3312	137.82	3069.19	619.11 (612.30–626.36)	239.47 (188.84–221.37)
Female	2721	174.56	4924.38	742.30 (733.07–752.86)	260.56 (233.98–294.11)
Other	16	233.15	860.26	590.84 (491.38–695.93)	202.74 (130.05–248.77)

[a] Bootstrapping method (simple test, N = 1000) [21].
[b] Standard Deviation.

3.3. Derivation of entrance surface dose from clinical EI

Based on the variations in clinical EI, dependent on patient thickness under the same exposure conditions, a conversion equation was developed to estimate the ESD using clinical EI. This conversion equation enables the utilization of clinical EI as a monitoring tool for patient dose. The average values of ESD and clinical EI measured corresponding to different phantom thicknesses are presented in Table 4.

The linear trend equation for the relationship between phantom thickness and ESD was determined as $y_{ESD} = 5.2133x_{thick} + 159.63$, while the linear trend equation for the relationship between phantom thickness and clinical EI was $y_{EI} = -99.551x_{thick} + 1247.8$. The relationship between clinical EI and ESD was derived by combining these two equations, as shown in equation (2).

$$ESD = -0.0524EI + 224.97\ [\mu Gy] \quad (2)$$

The ESD values for each patient were obtained by substituting the derived conversion equation into 6048 chest AP clinical data points. The resulting distribution of ESD values is presented in Fig. 6 as a histogram. Upon performing statistical analysis on the derived ESD distribution, the minimum value was found to be 38.59 μGy, the maximum value was 217.75 μGy, the average value was 189.67 μGy, and the 75th percentile value was 197.79 μGy.

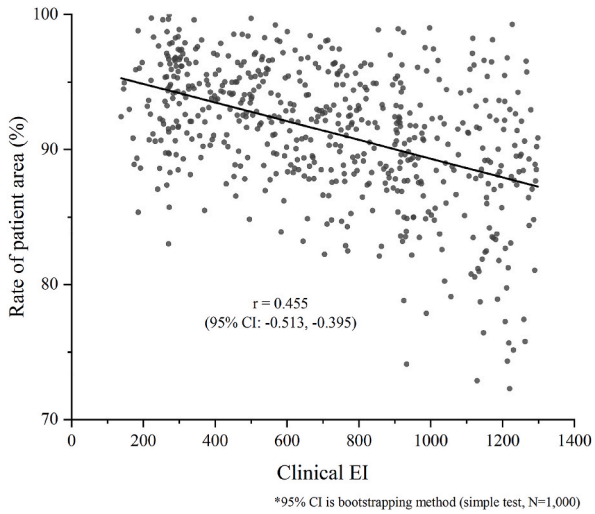

Fig. 4. Relationship between clinical exposure index and rate of patient area for binary images (582 data points were randomly selected in a sequential manner, starting from low to high values of the clinical exposure index).

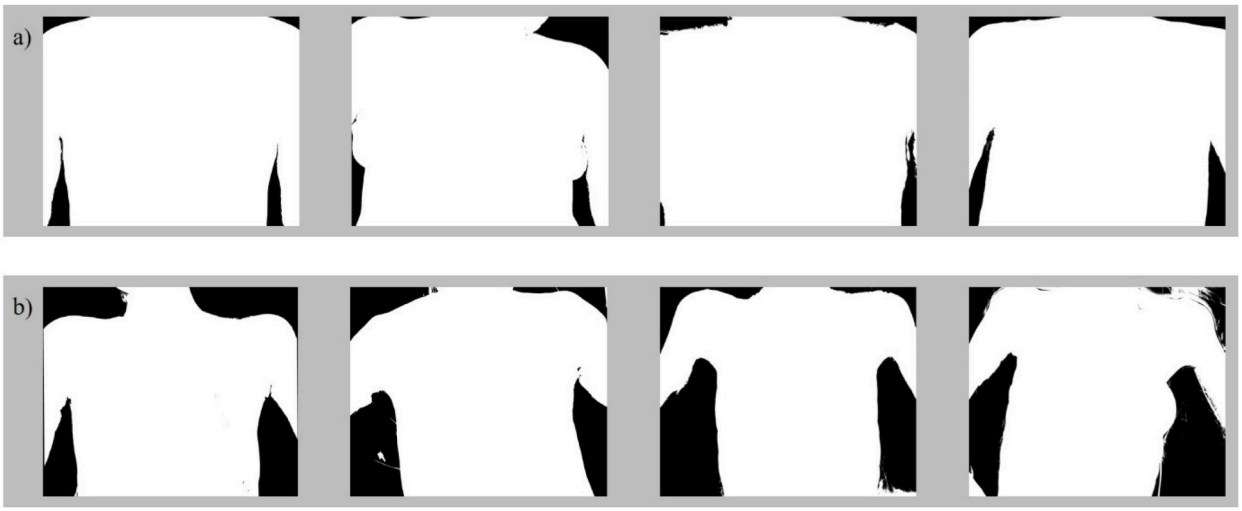

Fig. 5. Representative binary images of low clinical exposure index (a) and high clinical exposure index (b).

Table 4
Value of entrance surface dose and clinical exposure index according to the phantom thickness under the exposure conditions, which are tube voltage of 90 kVp and tube current exposure time product of 2.5 mAs.

Bolus thickness (cm)	ESD (μGy)	Clinical EI
0[a]	159.77	1234.37
2	170.97	1044.38
4	178.23	898.81
6	192.10	619.22

[a] Whole-body phantom only.

4. Discussion

In this study, the actual clinical application of the clinical EI was identified based on chest AP images taken with the mobile radiography and DR systems, including the clinical EI as per the IEC in DICOM information. The methods were reviewed to utilize the clinical EI as a patient dose-monitoring tool efficiently.

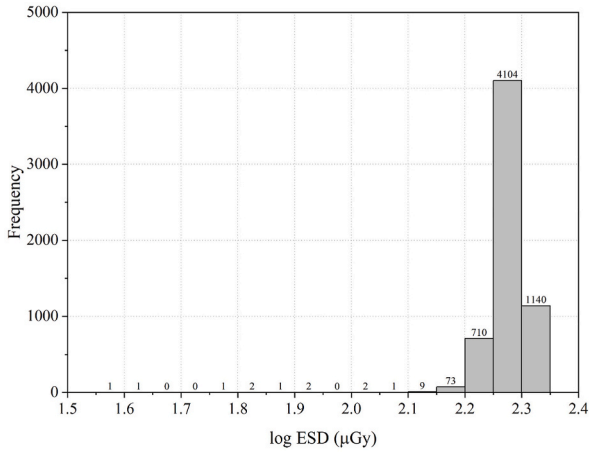

Fig. 6. Histogram of the number of data for each entrance surface dose derived from clinical exposure index of chest anteroposterior images taken under the exposure conditions of 90 kVp and 2.5 mAs with a mobile radiography system during the period of from June 1 to December 31 in 2021.

According to IEC 62494-1, the EI should be the same as the value obtained when the air kerma incident in μGy is multiplied by a constant of 100, as in equation (1), when exposed to the beam quality of RQA 5 without a subject, and the error rate should be within ±20 % [12,14]. This is defined as the calibration of EI, and applies equally to all DR system manufacturers [14]. Accordingly, EI is proportional to the incident dose on the detector [12,14–18]. The IEC standard notes that the EI may differ for each manufacturer and each type of examination in clinical protocols, but the proportional relationship with the incident dose on the detector does not change [12].

However, in the results of this study, the distribution of clinical EI values varied from a minimum of 137.82 to a maximum of 4924.38 for a total of 6048 data points despite the same exposure dose with exposure conditions of 90 kVp and 2.5 mAs. There was an intensively distributed clinical EI section; however, the difference was also large, ranging from 100 to 1300. In particular, in the case of data with a high clinical EI value of 2000 or more in the distribution, the patient's age was identified as an infant <1 year old.

In a previous study assessing the EI as a dose-monitoring tool, 1884 chest images of neonatal patients taken for 3 months with a mobile X-ray system were analyzed, and it was reported that the EI value was distributed in various ranges from 100 to 1600 [22].

The relationship between patient area on a chest AP image and clinical EI was analyzed in this study to understand the cause of the difference in clinical EI values despite the same exposure conidtions. All other conditions were the same, and the difference in the incident dose on the detector was due to patient factors, such as body shape and pathologic condition. In a previous study, when the AEC system was not applied, the EI value decreased as the phantom thickness increased. When the AEC system was used, the EI value was the same as the phantom thickness, but the entrance surface dose increased [18]. Therefore, the patient's thickness and body shape affect the clinical EI value in an environment such as this study where the AEC system is not used.

In this study, the relationship between the patient area on the chest AP image and clinical EI was investigated to confirm the change in clinical EI according to the actual patient's body shape. As a result, it was confirmed that there was a positive relationship between clinical EI and both the patient area and direct X-ray area. The smaller the patient, the higher the clinical EI value because the rate of the direct X-ray area is higher, and the dose incident on the detector is increased even under the same exposure field and conditions. These results are similar to those of a previous study [18].

In an actual clinical environment, even if the examination is performed under the same exposure conditions, the incident dose on the detector and image quality are different depending on the patient factors; therefore, the clinical EI values are inevitably distributed in various ways. In particular, it is difficult to monitor the patient dose using only the clinical EI value displayed on the console in a mobile radiography system where the AEC function is not used. In an X-ray room where a stationary radiography system is used, the incident dose on the detector of the chest examination is always constant because of the AEC function of the standing bucky [23]. Thus, it exhibits a different tendency from that of mobile radiography systems. Therefore, the method for deriving the clinical EI value according to whether the AEC system is applied should be distinguished. When a manufacturer decides how to calculate EI for a clinical examination, it is necessary to consider the image quality, such as noise, and patient factors, such as patient thickness.

In this study, focusing on the fact that clinical EI varies according to patient thickness when the AEC system is not applied [18], additional experiments were conducted to explore the potential use of clinical EI as a tool for monitoring patient dose. These experiments simulated chest AP imaging scenarios using the same mobile radiography system and exposure conditions as the clinical data. The anthropomorphic was utilized, and a bolus was added to increase the thickness. The ESD and clinical EI were measured corresponding to different thicknesses, and an equation was developed to derive ESD using clinical EI by establishing the relationships between phantom thickness and ESD and phantom thickness and clinical EI. The results of the measurements indicated that as the phantom thickness increased, the ESD increased while the clinical EI decreased. The calculated ESD values using the derived conversion equation showed a minimum error of 0.20 % and a maximum error of 0.42 % compared with the measured ESD values.

Internationally, the implementation of DRLs is recommended as part of the efforts to optimize patient dose in medical radiation,

according to the principle of as low as reasonably achievable (ALARA). In general radiography, it is recommended to set DRLs by ESD or dose area product (DAP), with the 75th percentile of the dose distribution commonly used as the reference level [24–26]. Notably, many countries have developed their national DRLs. In Korea, national DRLs for general radiography have been established and published since 2007, with ongoing additions and revisions to imaging protocol [27,28].

Upon applying the conversion equation derived in this study to calculate ESD through clinical EI, 6048 clinical data points were analyzed. The results showed that the derived ESD values decreased as the clinical EI values increased. Specifically, the 75th percentile value of the derived ESD distribution was 197.79 μGy. Comparing this value with the most recent national DRL for chest AP in Korea, which is 900 μGy [28], it can be evaluated that the medical institution providing the clinical data in this study effectively manages patient dose at lower level. However, the limitation of the comparison in this study is that the Korean national DRL value of chest AP does not distinguish between stationary and mobile radiography systems. The mobile radiography system differs from stationary radiography system in terms of several variables, such as the exposure condition, source-to-image receptor distance (SID) and the use of grids. Therefore, it is necessary to investigate DRL tailored specifically for mobile radiography system for future research. And it is important to note that DRLs serve as reference values rather than strict limits. If the patient's dose exceeds the DRL, it necessitates reviewing dose optimization strategies. Conversely, if the patient dose is lower than the DRL, it is essential to evaluate whether the obtained image quality provides sufficient diagnostic information due to the lower dose [24–26].

In general radiography, the DAP serves as an indicator for monitoring patient dose, and it can be conveniently measured using a DAP meter during patient examinations. However, the ESD cannot be measured using a dosimeter when examining patients; thus, it is difficult to identify in real-time [17,24–28]. The approach taken in this study, which involves inferring ESD through clinical EI, provides a means to monitor patient dose in real time without needing a dosimeter during the examination. However, it is essential to acknowledge that the method developed in this study considers only the patient thickness factor in calculating ESD. Additional factors, such as the SID and chest breadth, which influence changes in clinical EI and ESD, should be considered to evaluate ESD more accurately. By incorporating these factors, achieving a more precise assessment of ESD in clinical practice will be possible. Therefore, to practically utilize clinical EI as a monitoring tool for patient dose, a relationship that can directly calculate patient dose with clinical EI should be prepared by considering various related factors that affect it.

According to the IEC standard, the EI_T and deviation index (DI) are defined in addition to the EI. EI_T is the EI value when the target image quality of the corresponding detector is achieved, and DI is the deviation of the current EI value based on EI_T [12]. The degree of underexposure or overexposure can be determined by using the DI value. According to the derivation formula of DI as per IEC, there is an exposure difference when the DI is ±1 of approximately ±1.2 times that of EI_T, approximately ±1.6 times when the DI is ±2, and approximately ±2 times when the DI is ±3 [8,12,29]. Therefore, to use EI as a tool for determining the level of incident dose on the patient and obtaining the optimal image quality, it is essential to set the appropriate EI_T and assess the degree of exposure through the displayed DI value [15,17,19].

Previous studies have studied methods for setting the appropriate EI_T, such as setting the average value of the data taken for a certain period at their medical institution as the EI_T or setting the EI_T based on the national DRLs [15,17]. The EI_T provided by the DR system used in this study is a default value arbitrarily set by the manufacturer that can be reset according to the user's request [15]. In this system, the EI_T for the chest AP examination was 624. Among the data used for analysis, 223 cases had a DI of ±3 or more, which can be analyzed as low-quality images acquired due to underexposure or high-dose exposure due to overexposure in about 3.7 % of patients. However, as a result of this study, the EI, including the DICOM header, does not reflect the patient dose; thus, the actual dose to the patient indicates a different trend.

Consequently, various patients are examined in the actual clinical environment; however, the mobile radiography system mainly targets inpatients in medical institutions [30,31]. Thus, it is necessary to reflect pathological factors. Therefore, a clinical EI derivation method that reflect image quality, such as patient factors, should be considered to properly utilize clinical EI as an image quality and patient dose-monitoring tool. Furthermore, the appropriate EI_T should be set considering the characteristics of the medical institution where the DR system is used, target patients, and disease, and additional research on this should be conducted in the future.

Furthermore, similar to the approach adopted in this study, directly researching deriving patient doses using clinical EI and incorporating accumulated clinical EI data can lead to establishing appropriate EI_T values. By setting and monitoring these values accordingly, significant advancements are anticipated in reducing patient dose. Implementing such an approach allows medical institutions to monitor and regulate patient doses during examinations. This proactive approach promotes patient safety, minimizes unnecessary radiation exposure, and optimizes overall dose. Therefore, further research in this area holds great potential for enhancing radiation safety and image quality.

This study has a limitation in that it analyzed only a single protocol of a single radiography and DR system; however, it is meaningful in that it investigated the status of clinical EI for a mobile radiography system through more than 6000 actual clinical data. A total of 8045 chest AP images were collected for this study, and 6048 images taken at 90 kVp and 2.5 mAs, accounting for approximately 75.2 % of the total, were used for analysis. Clinical EI analysis of the remaining 24.8 % of the data should be performed in the future. It is important to note that the remaining chest AP data were acquired under exposure conditions that differ from the 90 kVp and 2.5 mAs. It is essential to gather additional information for each exposure condition to attain statistical significance and ensure the validity of the study findings.

It will be a more meaningful study if additional studies in various examinations or systems are conducted in the future to establish a general plan to utilize clinical EI as a patient dose-monitoring tool.

5. Conclusion

This study obtained, the clinical EI of chest AP images under the same exposure conditions with a mobile radiography system in an actual clinical environment. The results confirmed that the EI values were variously distributed at the same beam quality and exposure dose (mAs). The relationship between the direct X-ray area of the chest AP image and the clinical EI was analyzed by binarizing the image to determine the cause. It was confirmed that the higher the clinical EI, the larger the rate of the direct X-ray area. To effectively utilize the clinical EI as a patient dose monitoring tool, a conversion equation was developed to estimate patient dose based on clinical EI, considering variations in patient thickness under the same exposure conditions. As a result, ESD tended to decrease as clinical EI increased in an environment where the AEC system was not applied. Applying this conversion equation to clinical data made it feasible to estimate patient dose directly. In a clinical environment, the pixel value within the ROI of the image changes, even if the exposure conditions are the same, depending on the patient's body shape and thickness or pathological condition. Accordingly, to use the clinical EI of the mobile radiography system as a patient dose-monitoring tool more practically, the derivation method of clinical EI considers several factors, such as the relationship between patient factors. Furthermore, by directly inferring patient dose using clinical EI and establishing appropriate EI_T values based on this inference, it becomes possible to monitor patient dose in real time through DI value presented on the console of the DR system.

Declarations

This study was approved by the Institutional Review Board (IRB) of Dong-A University Hospital (DAUHIRB-22-035).

Data availability statement

Data included in article/supplementary material/referenced in article.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Hyemin Park: Formal analysis, Writing – original draft, Writing – review & editing, Investigation. **Jungsu Kim:** Formal analysis, Investigation, Resources. **Eun-Ju Kang:** Investigation, Project administration, Resources. **Yeji Kim:** Data curation, Software. **Hyejin Jo:** Data curation, Formal analysis. **Jin-Haeng Heo:** Formal analysis, Investigation. **Wonseok Yang:** Conceptualization, Methodology, Supervision. **Yongsu Yoon:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:This work was supported by the Dongseo University Research Fund of 2021 (DSU-20210010).

Acknowledgment

This work was supported by the Dongseo University Research Fund of 2021 (DSU-20210010).

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